Final Report

ASSESSMENT OF EPISODIC ACIDIFICATION IN THE SIERRA NEVADA, CALIFORNIA

by

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ABSTRACT

Monte-Carlo simulations were used to assess the short-term ANC depression of Sierra Nevada lakes due to acidic deposition events. The Episodic Event Model (EEM) was used to simulate snowmelt events as well as the summer dry deposition and rainfall events. The model assumes that during events, there are no rections occuring in the watershed which would neutralize the incoming acidity entering the lake. Consequently, the results of this study represent the worst case scenario. The parameters of the EEM model were derived from available databases. Spring snowmelt events were shown to have greater impacts on the water quality of the Sierran lakes than summer events. Under annual average loading conditions, no lake in Sierra Nevada is acidic although 29% of the lakes have ANC less than 40 $\mu eq/L$. During early snowmelt events simulated using present H^+ loading conditions, 79% ± 9% of the lakes will experience short-term ANC depressions to levels less than 40 $\mu eq/L$. The summer event simulations indicate that under present H^+ loading conditions, 31% of the lakes will have a short-term ANC depression to levels less than 40 $\mu eq/L$. The most critical parameters which control the magnitude of the ANC depressions during both snowmelt and summer critical events are a) the lake area to watershed area ratio and b) the volume of water in the mixing zone.

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DISCLAIMER

The material in this report in its entirety are those of the authors and not necessarily those of the California Air Resources Board. The mention of commercial products, their source or their use in connection with material reported herein is not to be construed as either actual or implied endorsement of such products.

CONCLUSIONS

A Monte-Carlo simulation technique was used for each of 168 lakes in Sierra Nevada to estimate the effect of acidic epidodes on the lake water quality. Random sampling was used on each regional parameter and the combination of values was used to drive the EEM model. Two hundred and fifty simulations were run to obtain an estimate of the mean and the standard deviation around the mean of the simulated lake ANC and thus provide an estimate of the uncertainty of the predictions.

Under annual average conditions, no lake in Sierra is acidic. However, 29% of the lakes have ANC less than 40 μeq/L. Sierra Nevada has the highest percentage of sensitive lakes to acid deposition of any other region in the United States except Florida. After a 20-day duration, early spring snowmelt event (present acidic loading conditions), it is expected that 79% ± 9% of the lakes will have ANC less than 40 μeq/L. The effects of doubling and halving the present levels of acidic loading were evaluated through scenario simulations. The results indicate that the lakes in Sierra Nevada are not very sensitive to changes in acid deposition, primarily due to the current low levels of acid deposition. The lakes would always be near zero in ANC during an event due to dilution by snowmelt runoff. The timing of the event effects the number of lakes with minimum ANC during the events of less than 40 μeq/L. It was found that 65% of the lakes will have ANC less than 40 μeq/L after a late spring, 20-day duration melt event.

The summer critical event simulations indicate that only a small portion of the lakes in Sierra Nevada (6-8% of the total population) should experience short-term depressions of ANC (less than 40 μeq/L) during a summer critical event. The magnitude of these depressions is less than the ANC depression caused by snowmelt critical events.

The geomorphological environment of the Sierra lakes makes them susceptible to acid deposition events. The acid loading levels in Sierra Nevada, California are low compared to those of Northeastern United States. Surveys have sampled no acid lakes under normal conditions. EEM simulations indicate that during an episodic event a large number of lakes will exhibit short-term depressions of pH and ANC.

RECOMMENDATIONS

An assessment of the lake resources-at-risk has been performed in this study. The uncertainty incorporated in the results lended increased confidence to the predictions. Continuing effort is required to attempt to reduce this uncertainty. Specifically the following studies should be undertaken.

1. Correlate the duration and severity of the snowmelt and summer episodic events with watershed features,
2. Apportion the severity of the events between dilution and acid deposition,
3. Treat dry deposition during the summer event by incorporating a soil compartment in the model,
4. Collect data that would minimize the uncertainty in predictions,
5. Validate the EEM model by utilizing data from other watersheds,
6. Assess the stream resources-at-risk to acid deposition, and
7. Modify the EEM model to evaluate the effects of nitrate, sulfate and ammonium on surface water quality.

The California Air Resources Board should utilize the results of this study to:

1. obtain an estimate of the lake resources at risk to episodic acidification under the worst case scenario,

2. design a field sampling network that would provide better data for acidification models, and
3. to utilize this framework of analysis for establishing emission standards.

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INTRODUCTION

There are 5000 lakes in California most of which are located in the Sierra (McCleneghan et al., 1985). The lakes in the Sierra Nevada of California are sensitive to increases in acidic deposition (Melack et al., 1985). The Sierra lakes are especially sensitive to acidic deposition because their watersheds are comprised of granitic bedrock and thin acid soils (McColl, 1981) and their waters are very dilute (Tonnessen, 1983; Melack et al., 1985; Landers et al., 1987). The lakes in the forested zone of the Sierra receive precipitation with a volume-weighted H^+ concentration of 6.5 μeq/L (wet only) (Stohlgren and Parsons, 1987). The present amount of acidic deposition in Sierra Nevada is relatively small compared to the northeastern United States (Eilers et al., 1987). However, acid deposition can occur as events that produce short-term depression of pH and ANC (Melack et al., 1987; Williams et al., this issue).

Lake resources-at-risk to acidic deposition in several regions of the United States and Europe have been assessed using of steady state models. The steady state Trickle-Down model has been used to assess the northeastern U.S.A. lake resources-at-risk to acidic deposition (Schnoor et al., 1986a) and upper midwestern lakes (Schnoor et al., 1986b). Using Henriksen's nomogram the risk of acidification to 700 Norwegian lakes was evaluated (Henriksen, 1979 and 1982). Thompson (1983) used the concept of the "cation denudation rate of a watershed" to evaluate the status of rivers in Nova Scotia and Newfoundland in Canada.

Evaluation of lake resources-at-risk during an episodic event on a regional basis has not been performed for any region of the U.S., Canada or Europe. The rapid release of acids from the snowpack during the spring thaw can cause a temporary drop in the pH and ANC of poorly buffered lakes and streams (Williams et al., this issue). This phenomenon can have adverse effects on aquatic biota (Gunn et al., 1986).

The objectives of this study are to develop a simplified episodic event model and to apply it to the lakes in the Sierra Nevada in California in order to evaluate the effect of acidic deposition events. Fig. 1 shows the location of the study area.

MODEL DEVELOPMENT

The episodic event model (EEM) is based on a mass balance for alkalinity in the lake. The model considers two types of episodic events: 1) the snowmelt event and 2) the summer rainfall event after a long period of dry deposition. In both time-periods (early or late spring and late summer), lakes in the Sierra are thermallly stratified (Melack et al., 1987; Sickman et al., 1989). During spring snowmelt the water at the bottom of the lake has a temperature of 3-4^{o}C and is more dense than the water near the ice/snowpack on the surface of the lake which has a temperature of 0-1^{o}C. A schematic of the EEM conceptualization is shown in Fig. 2.

EEM is a mixing model which simply dilutes epilimnion water with snowmelt or precipitation runoff water. The EEM model considers the lake epilimnion to be completely-mixed having a critical stratified volume, V_C. The model also assumes that during events, there are no reactions occurring in the terrestrial part of the watershed which would neutralize the acidity entering the lake. Melack et al., (1989) have shown that in the case of Emerald Lake watershed, the incoming to the lake acidity is neutralized even though the watershed is mostly exposed bedrock and during events the runoff contact time is short. Due to lack of more data, it was decided to utilize this assumption and thus to accept the results of this modeling effort as the worst case scenario. In EEM, steady flow was assumed. The analysis of the hydrologic data from the Emerald Lake watershed (Dracup et al., 1988) indicates that during an event the steady flow assumption holds. During peak snowmelt, the residence time of snowmelt water in Emerald Lake can be less than one day (Dozier et al., 1989). Given the above assumptions a simple input/output analysis for the lake epilimnion can be expressed mathematically as:

$$dA_L/dt = (Q_c/V_c)*L_{acy} - (Q_c/V_c)*A_L$$

where:

A_L = Lake alkalinity concentration, meq/m^3,

Q_c = Critical flow, m^3/day,

V_c = Lake critical stratified volume, m^3,

L_{acy} = Acidity concentration entering the lake, meq/m^3, and

t = Time step, day.

Solving eq (1) analytically, it yields:

$$A_L = A_{LO}*e^{-Qc*t/Vc} - L_{acy}*[1 - e^{-Qc*t/Vc}]$$

where:

A_{LO} = Initial lake alkalinity concentration, meq/m^3.

Since L_{acy} varies with time, the above equation is solved in a piecewise fashion with a very small time step.

PARAMETER AGGREGATION

The four parameters of the EEM (Q_C, V_C, L_{acy} and A_{LO}) are determined as follows:

1) **Critical Flow, Q_C:** Snowmelt is a dynamic phenomenon and its rates vary from day to day, and between years. Measurements for the evaluation of daily snowmelt rates in Sierra Nevada have been performed for two locations only: the Central Sierra Snow Laboratory where snow has been monitored for 15 years and the Emerald Lake watershed for 3 years (Dozier et al., 1989). The critical flow for the snowmelt event in this study can be approximated using average melt rates over the whole snowmelt period. Mathematically this can be expressed as:

$$Q_C = MR*AREA_T$$

where:

MR = Average melt rate, m/day

$AREA_T$ = Watershed surface area, m^2.

The critical flow for the summer event is equal to the precipitation event rate. This is a reasonable assumption because alpine watersheds in the Sierra Nevada are comprised largely of exposed bedrock, have thin pockets of soil and have a flashy hydrograph (Kattelmann et al., this issue). The critical flow is estimated as follows:

$$Q_C = PPT*AREA_T$$

where:

PPT = Precipitation event rate, m/day.

2) **Lake Critical Volume, V_c:** The critical stratified volume for both snowmelt and summer events can be approximated through the critical depth estimates as:

$$V_c = D_c*AREA_L$$

where:

D_c = Critical depth of epilimnion of stratified lake m,

and

$AREA_L$ = Lake surface area, m^2.

3) **Incoming Acidity Concentration, L_{acy}:** This parameter is the most difficult to estimate because it varies during the course of the event. During snowmelt, field and laboratory studies have shown that 50 to 80% of several ions are preferentially released in the first 30% of the melt water (Henriksen, 1979; Bales et al., 1989). The initial snowpack acidity concentration can be estimated as a volume-weighted average of the H^+ concentration in the precipitation during the snow season (Oct. 1 - Apr. 1). This is a good estimate of the pre-melt snowpack acidity since there is no enhancement of snowpack acidity due to vegetation. To estimate the daily flux of acidity to the lake from the snowpack, a modified version of the Goodison et al., (1986) model is used. The model computes the amount of acidity to be removed by melt as being proportional to the melt water removed. In mathematical terms, L_{acy} can be expressed as:

$$L_{acy} = [H^+]_0*[1 - (MR*t)/d_s]^n$$

where:

$[H^+]_0$ = Initial H^+ concentration in the snowpack before melt, meq/m^3,

MR = Average melt rate, m/day

d_s = Initial snow water equivalent (SWE), m, and

n = Constant of proportionality.

The parameter, d_s, can be estimated from snow course data. For California, the April 1st sampling period represents the deepest snow depth over a range of elevations (CCSS, 1985; CCSS, 1986).

The incoming acidity during the summer event can be estimated as follows:

$$L_{acy} = [(H^+_{dry} * T)/PPT] + H^+_{wet}$$

where:

H^+_{dry} = H^+ dry deposition flux, meq/m^2-day,

T = Interarrival time between two precipitation events, day

PPT = Precipitation event rate, m/day, and

H^+_{wet} = H^+ concentration of precipitation, meq/m^3.

4) Initial Lake Alkalinity Concentration, A_{LO}: This study uses data from the University of Iowa database (Nishida and Schnoor, 1989) that contains 198 Sierra lakes. This database contains data from the three lake surveys which have been conducted in Sierra Nevada: 1) the Western Lake Survey (Landers et al., 1987) conducted by the U.S. Environmantal Protection Agency, 2) the Statewide Survey of Aquatic Ecosystem Chemistry (McCleneghan et al., 1985) conducted by the California Department of Fish and Game in cooperation with the California Air Resources Board, and

3) the survey conducted by the University of California at Santa Barbara (Melack et al., 1985). These data can be used for analysis of both types of events.

REGIONALIZATION METHODOLOGY

To assess the impacts of episodic events of acidic deposition to lakes in the Sierra Nevada, California, the EEM model was used. Table 1 presents the data requirements of EEM for both snowmelt and summer events. Of the parameters in Table 1, lake ANC, lake surface area and watershed area are the only watershed specific parameters that are included in the database (Nishida and Schnoor, 1989). The other parameters were derived on a regional basis. Sierra Nevada was devided into three regions and existing precipitation monitoring stations were assigned to these areas. Division into subregions was necessary so the EEM model would reflect realistic distributions. Each watershed was assigned to a region determined by its proximity to the closest precipitation station. For each region, a distribution (normal or uniform) was derived for each of the non-watershed specific parameters.

The Monte-Carlo simulation technique was used for each lake to estimate the effect of the acidic episode on the lake. Random sampling was used on each parameter, (H_o^+, MR, D_s, n, d_c) and the combination of values was used to drive the EEM model. Two hundred and fifty simulations were run in order to obtain an estimate of the mean and the standard deviation around the mean of the simulated lake alkalinity. The Monte-Carlo technique provided an estimate of uncertainty on the prediction. Fig. 3 is a schematic of the Monte-Carlo simulation on each lake.

DATA ACQUISITION

a) Snowmelt Events:

There are a total of eight wet deposition stations in the Sierra operated by the California Air Resources Board (CARB) and by the National Atmospheric Deposition Program (NADP). The CARB data were collected between 1985 and 1987 (Blanchard et al., 1989), the NADP data were collected between 1980 and 1987 (NADP, 1987). For this study the Sierra Nevada was considered as three geographic regions. The division of the study area into subregions was necessary so the distributions of the regional parameters of the EEM model would be more realistic. Data from the Giant Forest station were used to characterize the South Sierra Region (SSR). Data from the Yosemite and Mammoth stations were applied to the Central Sierra Region (CSR). The South Lake Tahoe, Soda Springs and Quincy stations supplied precipitation data for the North Sierra Region (NSR).

Initial snow ANC was calculated from the volume-weighted H^+ concentration of precipitation between October 1st and March 31st. One value was obtained for each season for each station in each region. The normal distribution parameters (mean and standard deviation) were obtained from the calculated initial snow ANC seasonal averages.

Initial SWE was obtained by using the April 1st average snow water content for each station sampled by the California Department of Water Resources (CCSS, 1985 & 1986). The 1930-1975 April 1st, SWE station averages were used to obtain the mean and standard deviation for the initial snow depth normal distribution. Several stations were eliminated from each region because of their elevation. For instance in SSR, the lakes are located at an elevation greater than 2450 m. Thus, only the stations with greater than 2450 m elevation were used for the SSR d_s estimates.

Melt rates for each region were calculated using snow course data (CCSS, 1985 & 1986). Snow surveys in California are conducted once a month starting in January and ending in May or June. The April and May surveys for the 1985 and 1986 years were used to calculate the average melt rate for each station for each year because the sampling dates and SWE data were available. Normal distribution parameters were calculated for melt rate from these data. The upper and lower limits of the melting coefficient, n, were given by Goodison et al., (1986) as 1.9 to 4.5.

The early spring critical depth of lake stratification was obtained from the temperature profiles of 13 lakes (Lund, 1987; Melack et al., 1987; Sickman et al., 1989). The upper and lower limits of the critical depth were determined from these temperature profiles as 1.5 to 2.5 m. The upper and lower limits of the late spring critical depth were determined from lake temperature profiles measurements as between 3 and 7.5 m.

Table 2 presents the collected data for the South, Central and North Sierra Regions respectively. SSR precipitation stations receive roughly 15 to 20% less precipitation than CSR and NSR stations. They also have 25% higher melting rates. CSR and NSR receive the same amount of snow and exhibit approximately the same melting rates. The ANC in CSR is 40% higher than the other two regions which were comparable.

b) Summer Event:

The climatological data of California (NOAA, 1987) were used to estimate the intensity of precipitation during the summer months of July and August and the number of days between rainfall events (interarrival time). Data from the following stations were used to estimate the two parameters: Grant Grove, Lodgepole, Gem Lake, Ellery Lake, Twin Lake, Tahoe City, Truckee Ranger and Sagehen. The summer event model assumes that dry deposition has accumulated on surfaces in the watershed during the days between rainfall events. When a rain event occurs, the rain washes dry deposition from the watershed and into the lake where it is mixed in the epilimnion. A critical event is defined by the following criteria: 1) when the number of days between rainfall events was greater or equal to 10 days, or 2) when the amount of rainfall was greater than or equal to 1 cm. Given these criteria the events were selected through the period of 1983 to 1987 .

The distribution of H^+ concentration of the rainfall event was obtained by compiling all the July and August data from Sierra Nevada precipitation stations. The range of the H^+ dry deposition flux was obtained from Bytnerowicz et al., (1988). The range of the H^+ deposition flux deposited to Lodgepole (Pinus murrayara) and western white (Pinus monticola) pines was used.

Only the Western Lake Survey Lakes (101 lakes) were used to study the summer events because estimates of maximum lake depth were included in the survey. The summer critical depth of lake stratification was obtained from temperature profiles of lakes in the Sierra (Lund, 1987; Sickman et al., 1989). The critical depth was calculated as a percentage of the maximum depth of the lake. During the summer event simulation, for every lake, values of percent maximum depth (the critical depth) were obtained randomly from a uniform distribution. These values were multiplied by the estimates of maximum depth measured by EPA. In that way the critical depth of the lake for that simulation was obtained.

Table 3 presents the data used for the summer critical event simulations. The results apply to lakes with surface areas greater than one hectares since the Western Lake Survey was designed to sample lakes greater than one hectares.

The appendix contains a listing of the raw data utilized to develop the distribution of the parameters of the EEM model.

RESULTS AND DISCUSSION

a) Snowmelt Event Results

Two types of snowmelt event scenarios have been simulated. The first is referred to as the early spring (conservative) snowmelt event scenario. It is assumed that if snowmelt occurs in late March or early April (early thaw) then the lakes in Sierra would be most likely to be affected, because the depth of the upper stratified volume would be at a minimum. The second scenario is referred to as the late spring (liberal) snowmelt event scenario. In this scenario (which is more likely to occur), it is assumed that snowmelt will occur in late May and early June, when the upper stratified volume is at its maximum. The results of these two events give the upper and lower bounds of the lake resources-at-risk to acidic deposition in the Sierra Nevada.

This study considered 168 Sierra lakes. Under annual average conditions at observed initial ANC (Fig. 4), there are no acidic lakes in the Sierra Nevada. But the majority of the lakes are very dilute and have ANC values less than 100 μeq/L.

Monte-Carlo simulations were run for each of the 168 lakes. Subregions were designated such that 28 lakes were located in South Sierra (SSR), 105 in Central Sierra (CSR) and 36 in Northern Sierra (NSR). A typical example of the results is Emerald Lake. Emerald Lake is the Integrated Watershed Study site of the California Air Resources Board's Acid Deposition Program. Emerald Lake is located in Sequoia National Park. The lake has an annual average ANC of 29 $\mu eq/L$, a lake surface area of 2.72 ha and a watershed area of 120 ha. Fig. 5 presents the flows for the two major inflows and the outflow of Emerald Lake from a 1987 snowmelt event (4/10 - 4/23). An average melt rate of 0.40 ± 0.11 cm/day was calculated from these data. The initial snowmelt ANC (-4.6 $\mu eq/L$) was calculated from the H^+ concentration of snow. Fig. 6 shows the episodic event simulation under present loading conditions. The results indicate that the expected lowest lake ANC for a 20-day event is 18 $\mu eq/L$. The uncertainty of this result is ± 6.8 $\mu eq/L$ which is its standard deviation for the 250 Monte-Carlo simulations. This simulation constitutes a partial calibration of the EEM model. The field data used for this simulation are listed in Table 4.

The response of the lakes to the episodic event was variable. To summarize the responses, the lakes were examined in terms of initial ANC and lake-to-watershed surface area ratio. The lakes with the highest and lowest initial ANC and the lakes with the highest and lowest lake-to-watershed surface area ratio were selected for examination in each region.

Results for the SSR region are as follows. Mosquito 3 Lake has the highest watershed-to-lake area ratio (WLR) of 166.7 for the SSR region. It has an initial ANC of 44 $\mu eq/L$. During a 20-day duration event, its expected ANC is 0.4 $\mu eq/L$ having an uncertainty of ± 2.0 $\mu eq/L$. On the other hand, Hockett Lake (Center) has the lowest WLR of 2. Its initial ANC is 69 $\mu eq/L$ and the expected ANC during a 20-day event is 10 ± 9 $\mu eq/L$. Tableland Lake has the lowest initial ANC of 9 $\mu eq/L$ and model simulations predict the lake to have an ANC of 3 ± 2 μeq/L after a 20-day duration snowmelt event. A lake with no name (WLS code: 4A1-042) has the highest ANC of 178 μeq/L. Its episodic event ANC is expected to be 23 ± 18 μeq/L. The average WLR for the 28 lakes of the SSR region in the vicinity of the Giant Forest precipitation station is 14. The average initial ANC is 60 μeq/L, and the standard deviation is 38 μeq/L. The average ANC after a 20-day event is expected to be 16 ± 17 μeq/L. These results constitute the worst case scenario of an early spring melt. If the event happens in late spring, then the expected average ANC for these lakes would be 30 ± 22 μeq/L.

The CSR region exhibits different characteristics from the SSR region. The regional average initial ANC is 138 ± 240 μeq/L. On the average, the watershed area is 18 times greater than the lake surface area. The average ANC after a 20-day early spring snowmelt event is expected to be 21 ± 44 μeq/L. During a late spring melt event, the expected average ANC of the 105 lakes in the region is 45 ± 86 μeq/L. The higher average initial ANC indicates that the CSR lakes have better buffering mechanism than the SSR lakes. However, their geomorphological setting (higher WLR) makes them more susceptible to episodic events. Twin Lakes (South) has the highest WLR of 1000 and an initial ANC of 441.9 μeq/L. The expected ANC after a 20-day event (early spring) is expected to be 1 ± 19 μeq/L. Summit Lake has an initial ANC of 109.5 μeq/L and the lowest in the region WLR ratio of 3.8. During an early spring episodic event, the lake is expected to have an ANC of 85 ± 9 μeq/L. Twin Lakes (North) has the highest

ANC in the region of 1243.0 μeq/L (WLR of 25.6). Its early spring episodic event ANC is expected to be 267 ± 204 μeq/L. On the other hand, Parker Pass lake has the lowest ANC of 5.0 μeq/L (WLR of 34), and its episodic event ANC is expected to be -0.6 ± 1 μeq/L.

The NSR region contains 35 lakes. Of the three regions, it exhibits the lowest average WLR ratio, 8.0. The average initial ANC is 151.9 ± 194.3 μeq/L. The expected average ANC after a 20-day duration, early spring event is 70 ± 81 μeq/L and after a late spring event is 107 ± 129 μeq/L. Grass Lake has the highest WLR of 166.7 out of the 35 NSR lakes. Its initial ANC is 282.7 μeq/L and its early spring projected 20-day duration event ANC is 7 ± 29 μeq/L. Blue Lake exhibits an opposite response to Grass Lake. Blue lake has the lowest WLR of 2.7 in the region. Its initial ANC is 66.4 μeq/L, which is significantly lower than the Grass Lake initial ANC. The lake is expected to lose only 18% of its initial ANC during the early spring event. Waca Lake exhibits a similar response. The lake has the lowest initial ANC of 12.75 μeq/L and a watershed area 5 times greater than the lake area. After a 20-day early spring event the lake ANC is expected to be 9 ± 2 μeq/L. Smith Lake has the highest initial ANC of 1104.8 μeq/L in the NSR region (WLR of 17.8). Model predictions show that the lake would have an ANC of 366 ± 218 μeq/L after a 20-day early spring event.

To assess the lake resources-at-risk to acid deposition in the Sierra Nevada, the field data and the model simulation results are plotted as the cumulative percent of lakes having ANC less than a given value, versus the lake ANC. Fig. 3a presents the initial ANC distribution for the 168 lakes of this study. These data represent annual average conditions. Under these conditions, no lake in Sierra is acidic. However, 29% of the lakes have ANC less than 40 μeq/L. Sierra Nevada has a higher percentage of lakes with ANC less than 40 μeq/L than any other region in the United States except Florida. Fig. 7 presents the ANC distribution of lakes after a 20-day duration early spring snowmelt event. The expected value (mean) and ± one standard deviation curves are plotted as they were determined from the Monte-Carlo simulation results. The results assume that the present acidic loading conditions exist. After such an event, it is expected that 79% of the lakes will have ANC less than 40 μeq/L. The uncertainty due to the regional parameter estimates is that 71% to 88% of the lakes will have ANC less than 40 μeq/L. Fig. 8 shows the effects of doubling and halving the present levels of H^+ loading. These results indicate that the lakes in Sierra Nevada are not very sensitive to changes in acid deposition, primarily due to the current low levels of acidic loads. The lakes would always be near zero in ANC during an event due to dilution by snowmelt runoff, regardless of H^+ concentrations. The amount of acidity currently being deposited is not enough to change the situation dramatically. The timing of the event effects the amplitude of the ANC response. Fig. 9 is a comparison between the ANC distributions after an early versus a late spring melt event. It is found that 65% of the lakes will have ANC less than 40 μeq/L after a late spring, 20-

day duration melt event. This indicates that 15% of the lakes will be less affected if the event occurs in late rather than early spring.

b) Summer Event Results

Lakes used to simulate summer events were obtained from the EPA Western Lake Survey (Landers et al., 1987). One hundred and one Sierra lakes were considered. Under the annual average conditions reported in this database, there is no lake with ANC less than 0 μeq/L. Twenty four percent of the lakes have ANC between 0 and 40 μeq/L. When summer critical events occur under present H^+ loading conditions, then 3% of the lakes become acidic and 28% have ANC between 0 and 40 μeq/L. This indicates that an additional 8% of the lakes have a short-term ANC depression less than 40 μeq/L. Fig. 10 presents the cumulative distribution of lakes: a) under annual average conditions and b) under present H^+ loading critical event. Fig. 11 depicts the cumulative distribution of lakes under conditions of present loadings, half and double the present loadings (loading of H^+ during a critical event). At half the present loading only 1% of the lakes will recover to ANC levels greater than 40 μeq/L during the event. At double the present loading an additional 1% will have ANC less than 40 μeq/L.

The summer critical event simulations indicate that only a small portion of the lakes in Sierra Nevada (6-8% of the total population) should experience short-term depressions of ANC to critical levels (less than 40 μeq/L) during a summer critical event. The magnitude of these depressions are much less than the ANC depressions caused by a snowmelt critical event. The reason the magnitude of the ANC depressions is very small is because the summer stratified epilimnion of the lakes is much deeper than the mixing zone during the spring snowmelt. As in the case of the snowmelt events, the parameters which control the magnitude of the ANC depressions are a) the lake area to watershed area ratio and b) the volume of water in the mixing zone. It has been demonstrated that if the total H^+ loadings during an event were to double, only 1% additional lakes would reach ANC levels less than 40 μeq/L during the event.

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Table 1. EEM Model Data Requirements

A. Watershed Specific Data		
	A_{L0}	= Initial Lake ANC
	$AREA_L$	= Lake Area
	$AREA_T$	= Watershed Area
B. Regional Data		
1) Snowmelt Event		
	$[H^+]_0$	= Initial H^+ Concentration of Snow
	MR	= Melt Rate
	d_s	= Initial Snow Depth
	D_c	= Lake Critical Depth
	n	= Proportionality constant
2) Summer Event		
	H^+_{dry}	= H^+ Flux in Dry Deposition
	PPT	= Precipitation Intensity
	H^+_{wet}	= H^+ Concentration in Precipitation
	T	= Event Interarrival Time
	D_{pc}	= Percent of Maximum Lake Critical Depth

TABLE 2. EEM Snowmelt Episodic Event Data

a) Normally Distributed Parameters

Parameter	Mean	Standard Deviation	No. of Data	Reference
South Sierra Nevada Region				
$[H^+]_0$ (meq/m^3)	6.74	2.06	9	NADP, 1987 and Blanchard et al., 1989
MR (cm/d)	1.59	0.73	17*	CCSS,1985 & 1986
d_s (cm)	66.40	19.50	38*	CCSS,1985 & 1986
Central Sierra Nevada Region				
$[H^+]_0$ (meq/m^3)	9.71	5.36	9	NADP, 1987 and Blanchard et al., 1989
MR (cm/d)	1.28	0.44	35**	CCSS, 1985 & 1986
d_s (cm)	80.50	22.90	48**	CCSS, 1985 & 1986
North Sierra Nevada Region				
$[H^+]_0$ (meq/m^3)	6.20	1.71	6	NADP, 1987 and Blanchard et al., 1989
MR (cm/d)	1.25	0.43	123**	CCSS,1985 & 1986
d_s (cm)	80.90	34.50	92**	CCSS,1985 & 1986

b) Uniformly Distributed Parameters

Parameter	Lower Limit	Upper Limit	No. of Data	Reference
n	1.9	4.5	--	Goodison et. al., 1986
Early Spring Event				
D_c (m)	1.5	2.5	13	Lund, 1987; Sickman et al., 1989
Late Spring Event				
D_c (m)	3.0	7.5	9	Lund, 1987; Sickman et al., 1989

* Only stations with elevations higher than 2450 m were used.
** Only stations with elevations higher than 1500 m were used.

TABLE 3. EEM Summer Episodic Event Data

a) Normally Distributed Parameters

Parameter	Mean	Standard Deviation	No. of Data
PPT (cm)	0.99	1.27	87
H^{+}_{wet} (meq/m^3)	16.06	12.33	31

b) Uniformly Distributed Parameters

Parameter	Lower Limit	Upper Limit	No. of Data
H^{+}_{dry} (meq/m^2/day)	0.0	6.15	16
T (days)	1.0	84.0	87
D_{pc} (%)	15.0	56.0	14

TABLE 4. Emerald Lake Snowmelt Episodic Event Data

a) Normally Distributed Parameters

Parameter	Mean	Standard Deviation	Reference
$[H^+]_0$ (meq/m^3)	4.60	0.00	Dozier et al., 1987; Dozier et al., 1989
MR (cm/d)	0.40	0.11	Melack et al., 1987; Melack et al., 1989
d_s (cm)	78.00	0.00	Melack et al., 1987; Melack et al., 1989

b) Uniformly Distributed Parameters

Parameter	Lower Limit	Upper Limit	Reference
n	1.9	4.5	Goodison et. al., 1986
D_c (m)	3.0	3.0	Melack et al.,1987

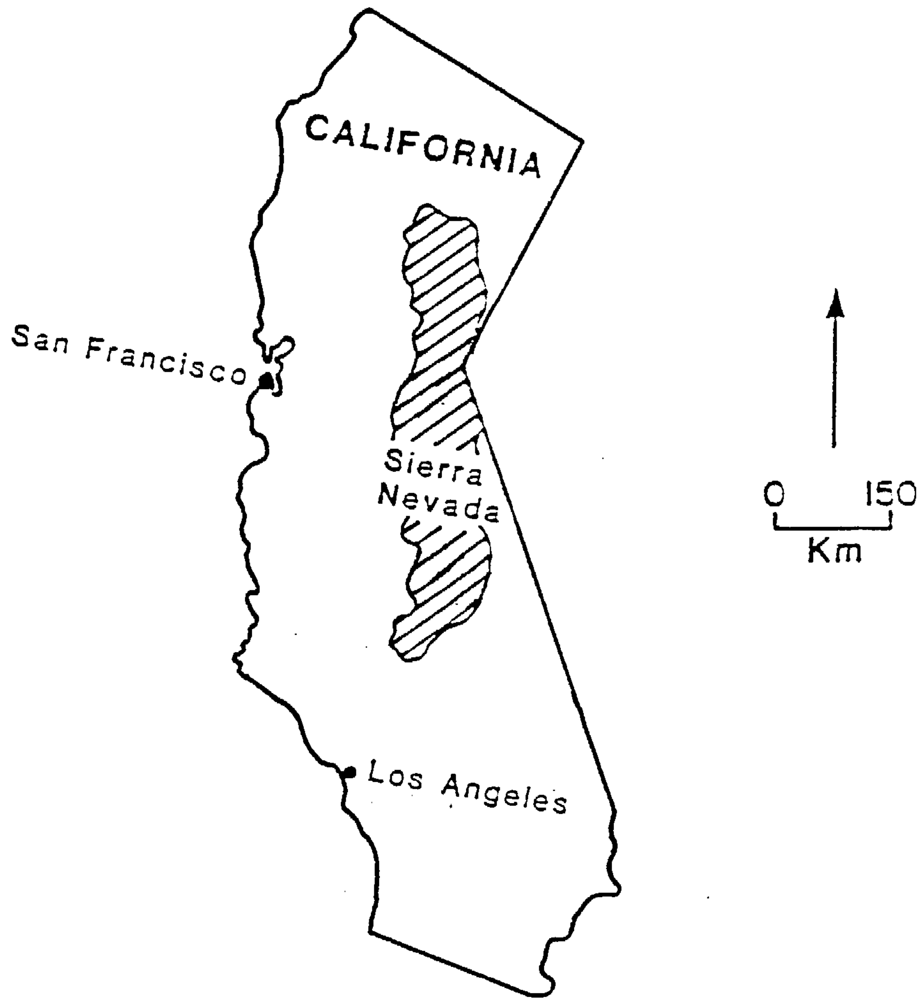

Fig. 1. Location of Study Area

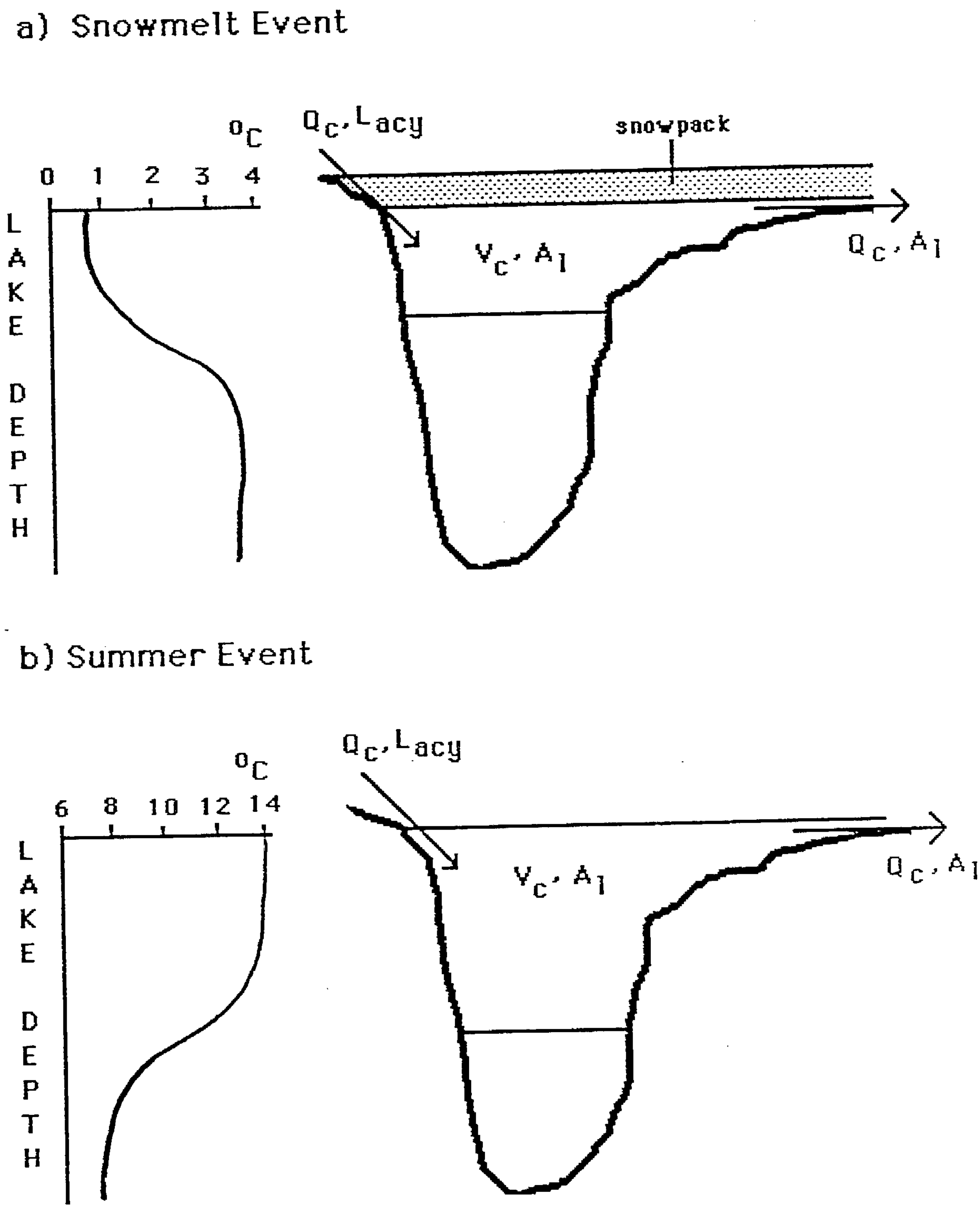

Fig. 2. Schematic conceptualization of the Episodic Event Model

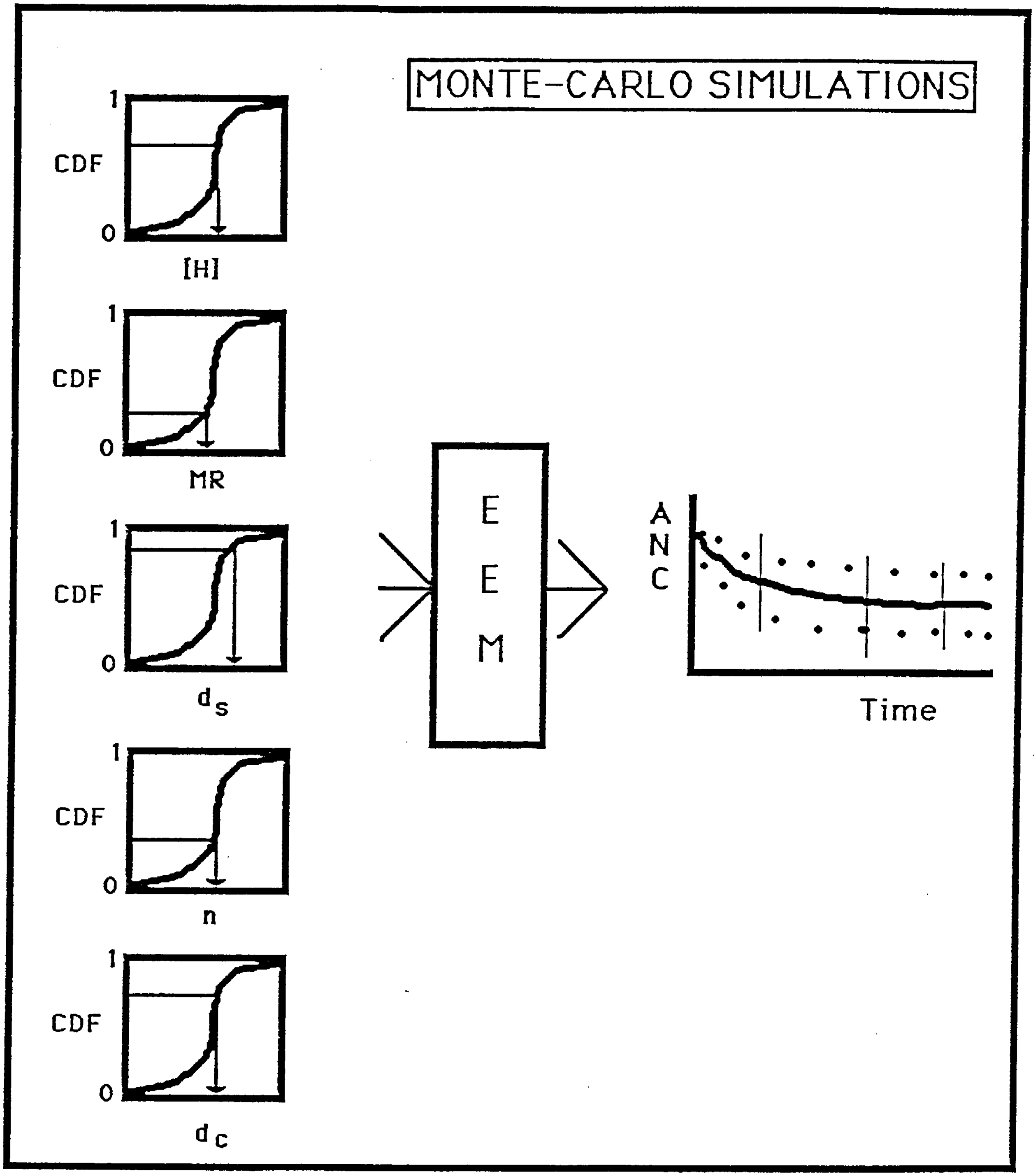

Fig. 3. Schematic of the Monte Carlo simulation technique

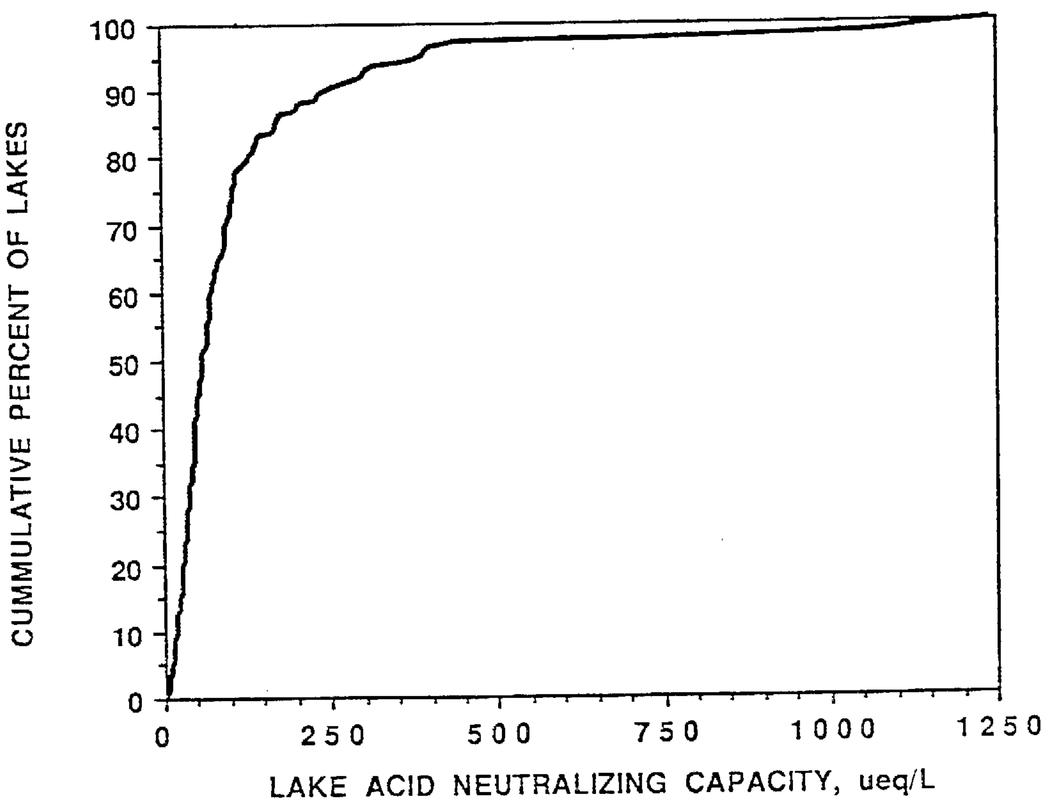

Fig. 4. Annual average distribution of ANC of 168 lakes in Sierra

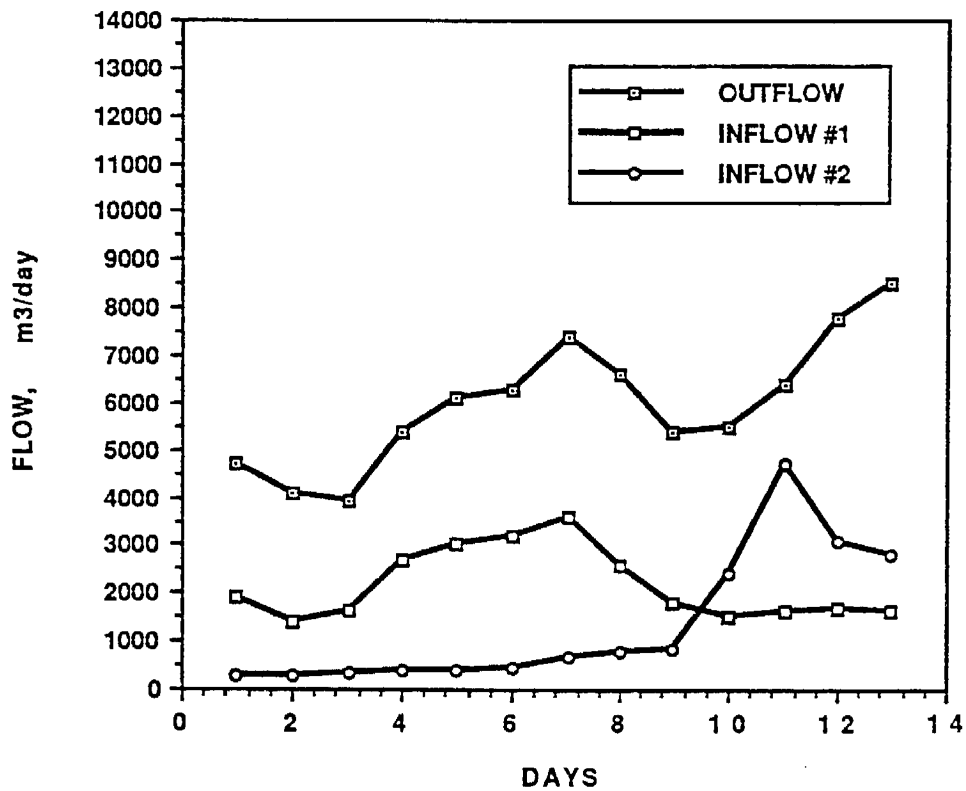

Fig. 5. Emerald Lake inflow and outflow stream field data (snowmelt event: 4/10 - 4/23/1987)

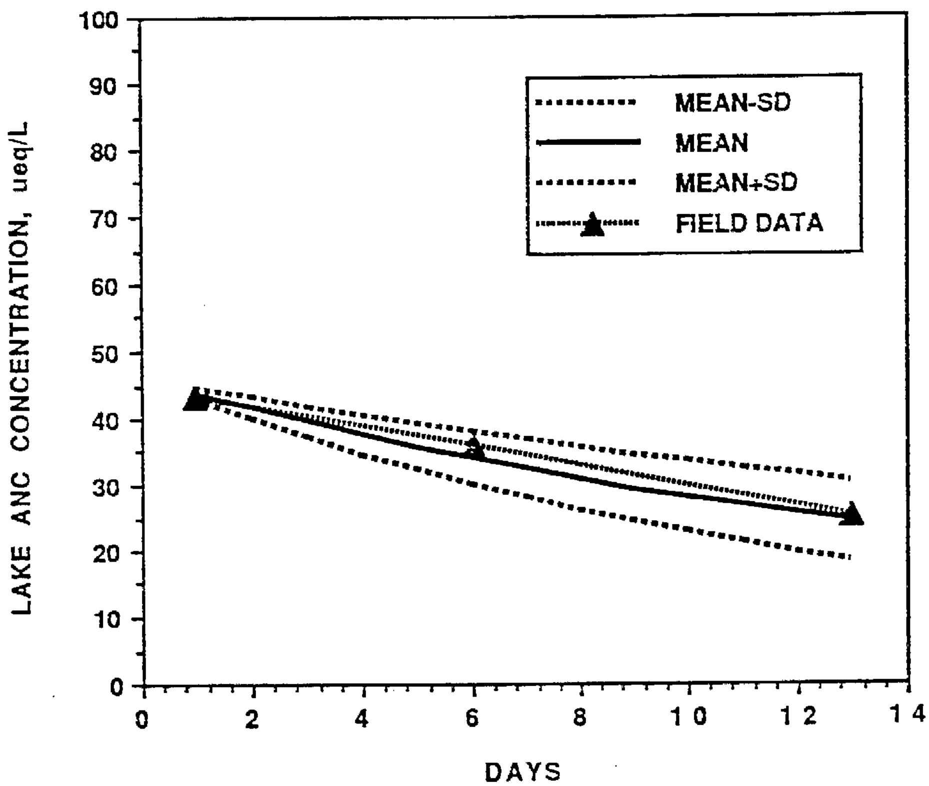

Fig. 6. Comparison of outflow ANC field data and model simulation for Emerald Lake

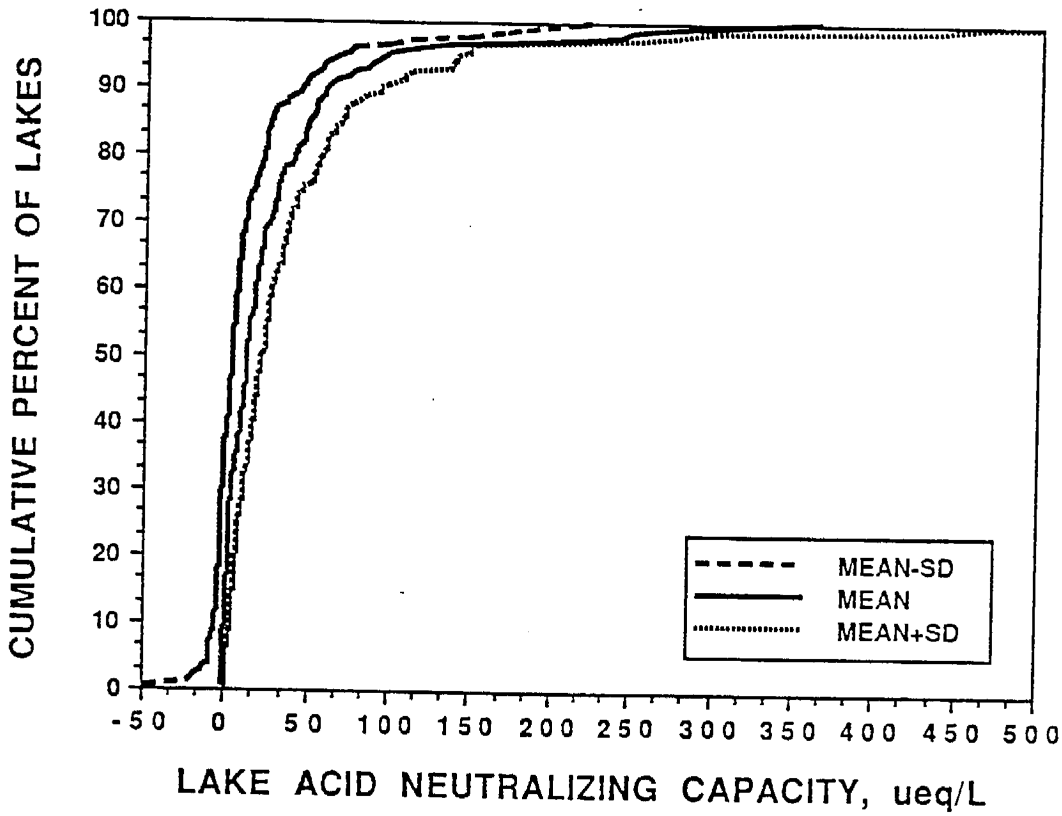

Fig. 7. ANC distribution of lakes under present loading scenario and early spring conditions

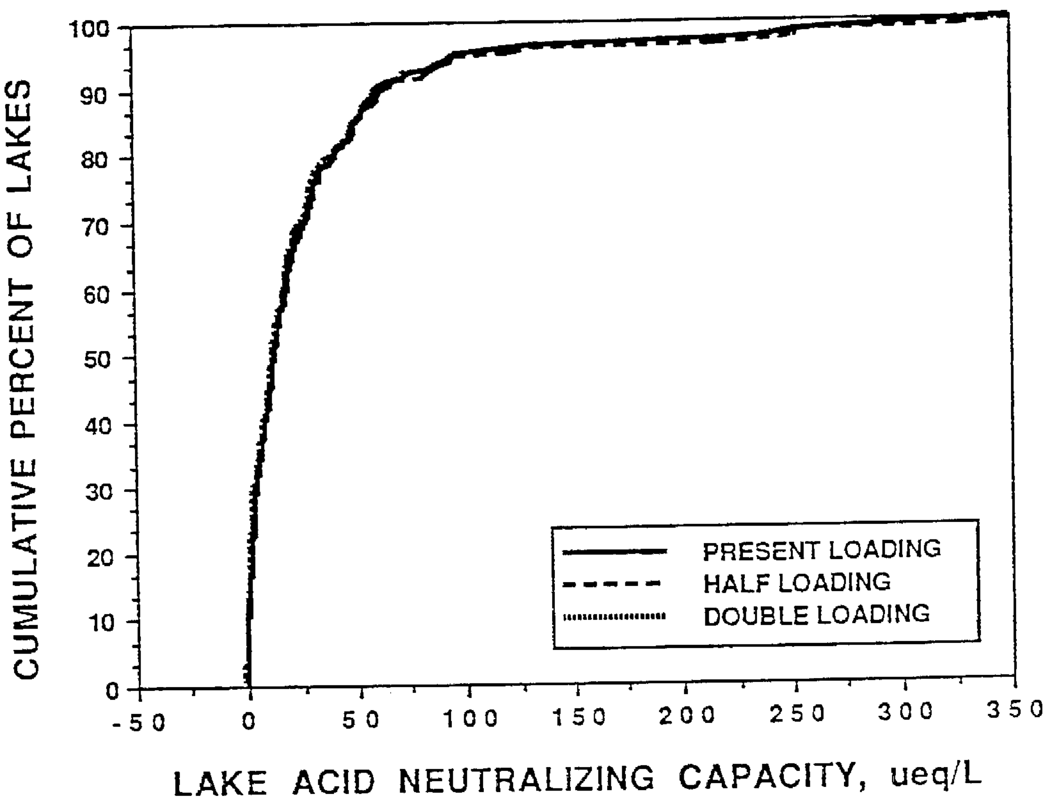

Fig. 8. ANC distribution of lakes under various loading scenarios and early spring conditions

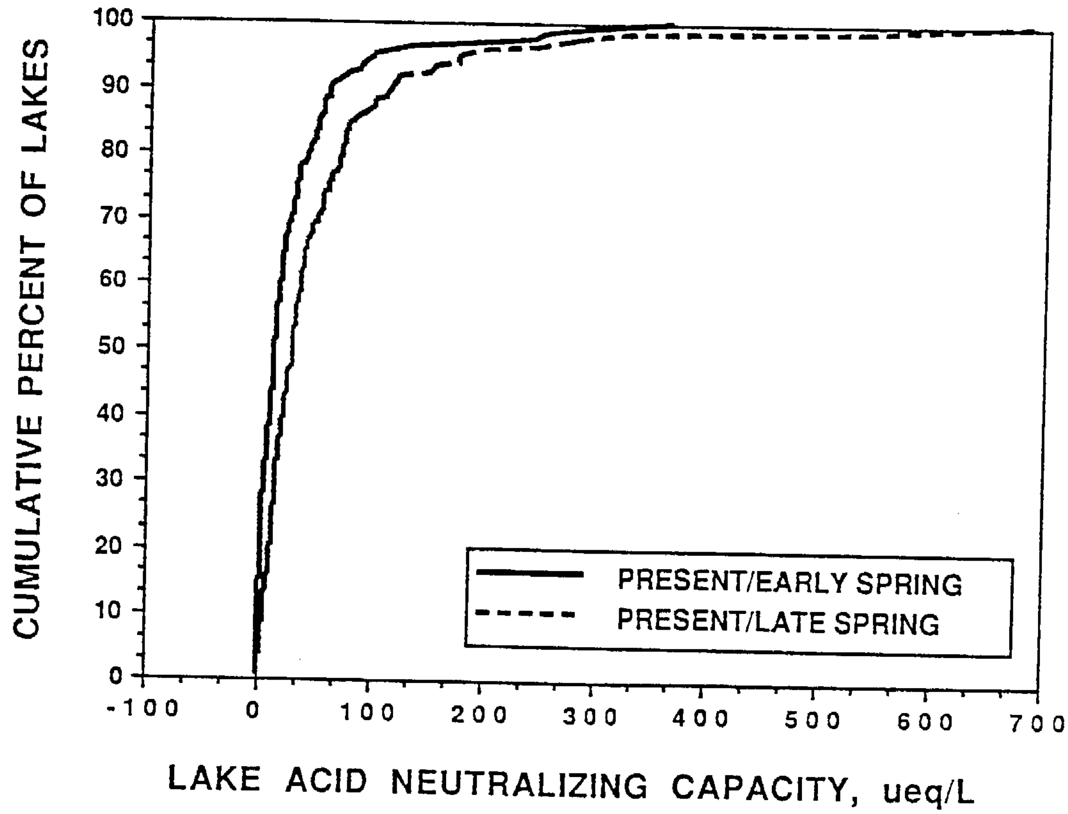

Fig. 9. Comparisons of ANC distributions of lakes under early versus late spring conditions and present loading scenario

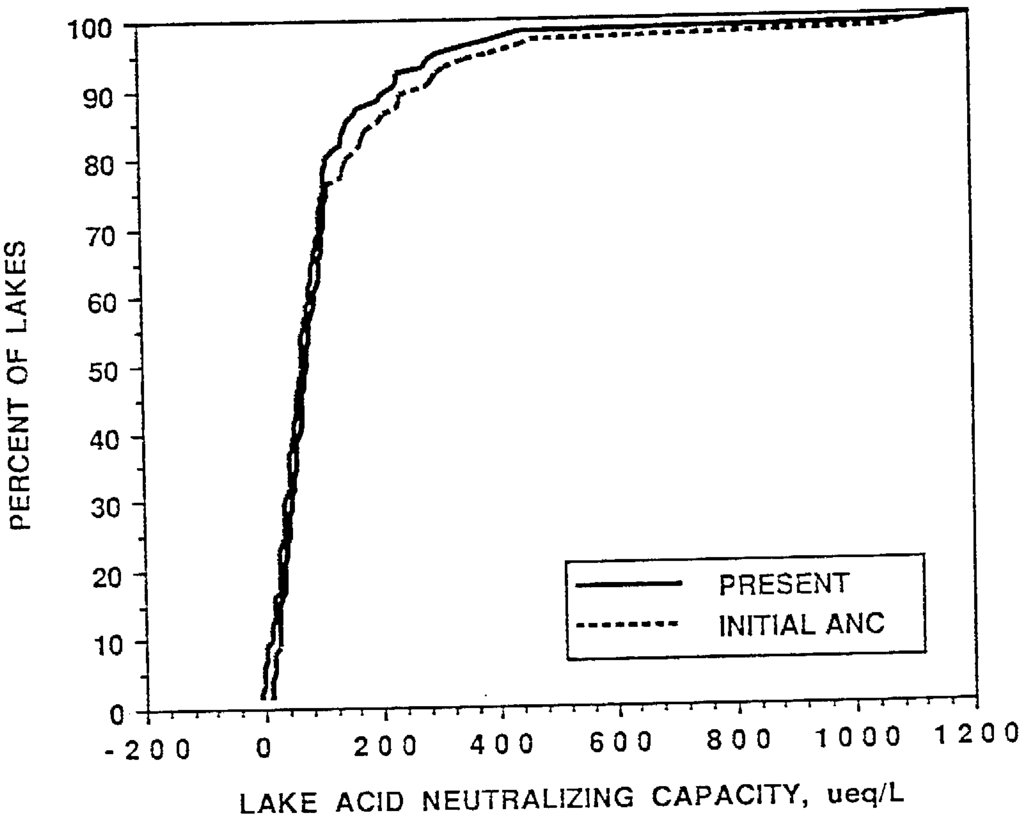

Fig. 10. Summer Episodic Event: Comparison of annual average ANC distribution of 101 lakes and ANC distribution under present loading scenario

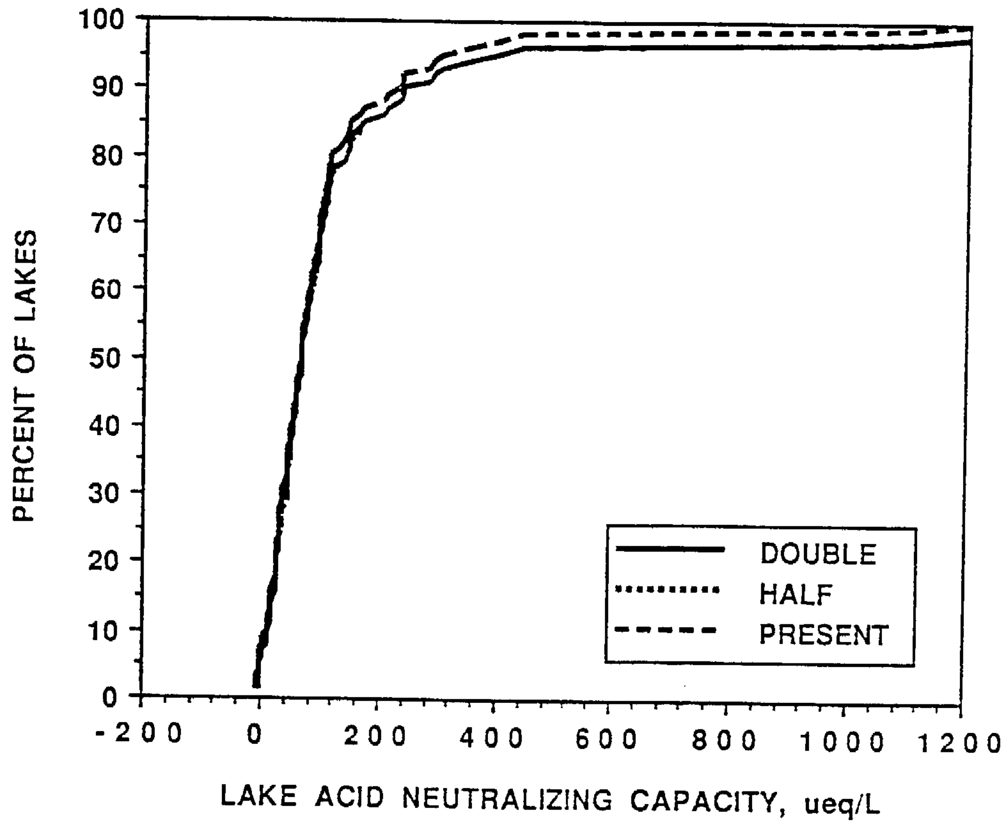

Fig. 11. Summer Episodic Event: ANC distribution of lakes under various loading scenarios

APPENDIX A

1. HYDROGEN ION CONCENTRATION OF PRECIPITATION DURING THE SNOW SEASON

The concentration of hydrogen ion is the precipitation volume weighted average of the events occuring between Oct. 1 and March 31 in units of microequivalents per liter. "n" refers to the number of data existing for that season.

LOCATION	SEASON	HYDROGEN ION (ueq/L)	n	REFERENCE
Giant Forest (*)	1980-81	7.72	8	NADP/NTN
Giant Forest (*)	1981-82	10.47	16	NADP/NTN
Giant Forest (*)	1982-83	3.89	10	NADP/NTN
Giant Forest (*)	1983-84	8.80	11	NADP/NTN
Giant Forest (*)	1984-85	5.48	11	NADP/NTN
Giant Forest (*)	1985-86	6.00	10	NADP/NTN
Giant Forest (*)	1986-87	4.83	12	NADP/NTN
Yosemite Station (@)	1981-82	6.25	9	NADP/NTN
Yosemite Station (@)	1982-83	10.72	20	NADP/NTN
Yosemite Station (@)	1983-84	21.68	14	NADP/NTN
Yosemite Station (@)	1984-85	7.47	13	NADP/NTN
Yosemite Station (@)	1986-87	11.57	11	NADP/NTN
Yosemite Station (@)	1985-86	10.97	4	CARB
Yosemite Station (@)	1986-87	10.42	12	CARB
Mammoth Mountain (@)	1985-86	5.04	14	CARB
Mommoth Mountain (@)	1986-87	3.26	6	CARB
Lake Tahoe (!)	1985-86	4.53	15	CARB
Lake Tahoe (!)	1986-87	5.01	11	CARB
Soda Springs (!)	1985-86	4.58	18	CARB
Soda Springs (!)	1986-87	7.68	17	CARB
Quincy (!)	1985-86	8.41	10	CARB
Quincy (!)	1986-87	7.00	13	CARB

HYDROGEN ION CONCENTRATION DISTRIBUTIONS:

	Mean (ueq/L)	Standard Deviation	Number of Seasons
South Sierra (*)	6.74	2.35	7
Central Sierra (@)	9.71	5.36	9
North (!)	6.2	1.71	6

2. SNOWMELT EPIDOSIC EVENT
SOUTH SIERRA REGION
(SSR)
MELT RATE

STATION	MELT RATE 1985 (in/day)	1986 (in/day)
Blackcap Basin	0.77	0.59
Rattlesnake Creek Basin	0.44	0.93
Upper Burnt Corral Meadow	0.27	0.77
Vidette Meadow	0.30	-
Round Corral	0.49	1.09
Courtright	0.33	-
Statum Meadow	0.60	-
Dodsons Meadow	0.58	1.19
Panther Meadow	0.55	-
Hockett Meadow	0.34	-
Long Meadow	-	1.00
Mineral King	-	0.42

3. SNOWMELT EPISODIC EVENT
CENTRAL SIERRA REGION
(CSR)
MELT RATE

STATION	MELT RATE 1985 (in/day)	1986 (in/day)
Tuolumne Meadows	0.24	0.37
Dodge Ridge	0.42	-
Ostrander Lake	0.34	0.47
Piute Pass	0.19	-
Kaiser Pass	0.35	-
Cora Lakes	0.66	0.48
Snow Flat	-	0.21
Huntington Lake	0.66	-
Jackass Meadow	0.64	0.89
Chiquito Creek	0.64	0.65
Poison Meadow	0.75	0.49
Florence Lake	0.24	-
Paradise	-	0.32
Kerrick Corral	0.69	0.63
Vernon Lake	0.56	0.61
Beehive Meadow	0.60	0.59
Bell Meadow	-	0.31
Gin Flat	0.60	0.56
Peregoy Meadows	-	0.21
Chilkoot Lake	0.68	0.58
Chilkoot Meadows	0.50	0.44
Clover Meadow	0.59	0.51

4. SNOWMELT EPISODIC EVENT
NORTH SIERRA REGION
(NSR)
MELT RATE

Station	MELT RATE 1985 (in/day)	1986 (in/day)
Lower Lassen Peak	0.22	-
Upper Carson Pass	0.58	0.37
Lower Carson Pass	0.59	0.46
Caples Lake	0.49	0.49
Alpha	0.63	0.58
Lost Corner Mountain	0.60	0.52
Highland Meadow	0.32	0.18
Tragedy Creek	0.21	0.30
Blue Lakes	0.41	0.24
Wheeler Lake	0.29	0.33
Pacific Valley	0.52	0.39
Deadman Creek	0.30	-
Clark Fork Meadow	0.35	-
Giannelli Meadow	0.38	-
Lower Relief Valley	0.49	0.29
Soda Creek Flat	0.63	0.36
Stanislaus Meadow	0.51	0.19
Eagle Meadow	0.55	0.45
Herring Creek	0.54	-

5. LAKE STRATIFICATION DEPTH

LAKE NAME	DATE	DEPTH (m)	Reference
LATE SPRING MELT			
Lake Agnew	29-Jun-87	5.0	Lund
Gem Lake	29-Jun-87	5.0	Lund
Lundy Lake	25-Jun-87	4.0	Lund
Sabrina Lake	24-Jun-86	3.0	Lund
Sabrina Lake	30-Jun-87	7.0	Lund
South Lake	24-Jun-86	4.0	Lund
South Lake	30-Jun-87	7.5	Lund
Waugh	29-Jun-87	3.5	Lund
Ellery	25-Jun-86	3.0	Lund
SUMMER			
Lake Agnew	26-Aug-86	9.5	Lund
Lake Agnew	25-Aug-87	10.5	Lund
Gem Lake	08-Jul-86	6.5	Lund
Gem Lake	25-Aug-87	8.5	Lund
Lundy Lake	25-Aug-86	4.0	Lund
Lundy Lake	23-Aug-87	6.5	Lund
Sabrina Lake	19-Aug-86	8.5	Lund
Sabrina Lake	24-Aug-87	10.5	Lund
Saddlebag Lake	25-Aug-86	5.5	Lund
Saddlebag Lake	29-Aug-87	10.5	Lund
South Lake	24-Aug-87	17.0	Lund
Tioga Lake	25-Aug-86	6.5	Lund
Tioga Lake	23-Aug-87	6.0	Lund
Waugh Lake	26-Aug-86	4.5	Lund
EARLY SPRING MELT			
Gem Lake	25-Mar-87	2.0	Lund
Sabrina Lake	18-Mar-87	1.5	Lund
Saddlebag Lake	25-Mar-87	2.0	Lund
South Lake	26-Mar-87	2.5	Lund
Tioga Lake	25-Mar-87	2.0	Lund
Ellery Lake	25-Mar-87	2.5	Lund
Emerald Lake	02-Mar-86	2.0	Melack
Crystal Lake	12-Mar-87	2.0	Sickman
Pear Lake	08-Mar-88	1.5	Sickman
Pear Lake	29-Mar-88	1.5	Sickman
Ruby Lake	11-Mar-87	2.0	Sickman
Topaz Lake	08-Mar-88	2.0	Sickman
Topaz Lake	29-Mar-88	2.0	Sickman

6. SNOW SURVEY DATA
AVERAGE WATER CONTENT OF SNOW, INCHES
APRIL 1st MEASUREMENTS
SOUTH SIERRA REGION (SSR)
(CCSS, 1985 AND 1986)

AREA, DRAINAGE BASIN, AND SNOW COURSE	CALIF. NUMBR. (1)	ELEV IN FEET	RECORD. BEGAN	AV APR 1 WC (2)
CENTRAL VALLEY AREA				
KINGS RIVER				
BISHOP PASS	222*	11200	1930	32.6
CHARLOTTE RIDGE	299*	10700	1955	32.7
BULLFROG LAKE	307	10650	1932	30.8
BENCH LAKE	398	10600	1973	30.9
BLACKCAP BASIN	223*	10300	1930	34.1
RATTLESNAKE CREEK BASIN	396	9900	1973	40.7
BEARD MEADOW	225*	9800	1930	32.8
UPPER BURNT CORRAL MDW	224*	9700	1927	36.3
SCENIC MEADOW	397	9650	1973	27.0
VIDETTE MEADOW	309	9500	1956	22.3
ROUND CORRAL	229*	9000	1938	35.8
ROWELL MEADOW	226*	8850	1930	27.6
WOODCHUCK MEADOW	227*	8800	1930	31.9
LONG MEADOW	232*	8500	1930	29.1
COURTRIGHT	426	8350	1982	37.4
STATUM MEADOW	233*	8300	1930	32.6
HELMS MEADOW	230*	8250	1930	26.9
POST CORRAL MEADOW	234	8200	1930	26.7
DODSONS MEADOW	308*	8050	1956	29.0

AREA, DRAINAGE BASIN, AND SNOW COURSE	CALIF. NUMBR. (1)	ELEV IN FEET	RECORD. BEGAN	AV APR 1 WC (2)
CENTRAL VALLEY AREA				
KAWEAH RIVER				
FAREWELL GAP	292	9500	1952	33.9
PANTHER MEADOW	243	8600	1925	35.9
HOCKETT MEADOWS	244	8500	1930	29.3
MINERAL KING	245	8000	1948	20.9
KERN RIVER				
BIGHORN PLATEAU	250*	11350	1949	22.4
COTTONWOOD PASS	251*	11050	1948	14.1
SIBERIAN PASS	252*	10900	1948	18.8
CRABTREE MEADOW	253*	10700	1949	19.3
GUYOT FLAT	254*	10650	1949	20.4
SANDY MEADOWS	275*	10650	1949	18.7
TYNDALL CREEK	255*	10650	1949	18.8
BIG WHITNEY MEADOW	257*	9750	1948	17.0
ROCK CREEK	256*	9600	1949	17.6
ROUND MEADOW	258*	9000	1930	26.1
RAMSHAW MEADOWS	259*	8700	1930	12.0
LITTLE WHITNEY MEADOW	260*	8500	1930	14.2
CASA VIEJA MEADOWS	262*	8400	1930	20.3
QUINN RANGER STATION	264*	8350	1930	20.8
BONITA MEADOWS	261*	8200	1930	14.3

7. SNOW SURVEY DATA
AVERAGE WATER CONTENT OF SNOW, INCHES
APRIL 1st MEASUREMENTS
CENTRAL SIERRA REGION (CSR)
(CCSS, 1985 AND 1986)

AREA, DRAINAGE BASIN, AND SNOW COURSE	CALIF. NUMBR. (1)	ELEV IN FEET	RECORD BEGAN	AV APR 1 WC (2)
CENTRAL VALLEY AREA				
TUOLUMNE RIVER				
DANA MEADOWS	157*	9850	1926	30.0
RAFFERTY MEADOWS	158	9400	1948	31.3
BOND PASS	159*	9300	1948	44.5
NEW GRACE MEADOW	368*	8900	1966	51.3
TUOLUMNE MEADOWS	161	8600	1930	22.6
HORSE MEADOW	162*	8400	1948	48.6
DODGE RIDGE	379	8150	1970	40.8
WILMER LAKE	163*	8000	1946	43.7
SACHSE SPRINGS	165*	7900	1948	39.1
HUCKLEBERRY LAKE	166*	7800	1948	42.8
SPOTTED FAWN	164*	7800	1948	46.8
PARADISE	167*	7700	1946	40.6
KERRICK CORRAL	348	7000	1961	23.2
UPPER KIBBIE RIDGE	168*	6700	1937	20.8
LOWER KIBBIE RIDGE	173*	6700	1937	28.3
VERNON LAKE	169*	6700	1947	24.1
BEEHIVE MEADOW	171*	6500	1930	26.4
BELL MEADOW	172	6500	1937	18.4
MERCED RIVER				
SNOW FLAT	176	8700	1930	43.4
OSTRANDER LAKE	177	8200	1938	34.4
LAKE TENAYA	178	8150	1930	33.2
GIN FLAT	179	7000	1930	33.7
PEREGOY MEADOWS	180	7000	1931	31.9

AREA, DRAINAGE BASIN, AND SNOW COURSE	CALIF. NUMBR. (1)	ELEV IN FEET	RECORD BEGAN	AV APR 1 WC (2)
CENTRAL VALLEY AREA				
SAN JOAQUIN RIVER				
MONO PASS	182	11450	1950	31.9
PIUTE PASS	183	11300	1930	35.7
EMERALD LAKE	184*	10600	1944	35.8
PIONEER BASIN	276*	10400	1949	34.6
HEART LAKE	185*	10100	1940	28.0
VOLCANIC KNOB	186*	10100	1946	30.1
ROSE MARIE	187*	10000	1946	29.1
COLBY MEADOW	188*	9700	1944	23.0
AGNEW PASS	189*	9450	1930	31.9
DUTCH LAKE	191*	9100	1938	29.0
KAISER PASS	190*	9100	1930	38.5
COYOTE LAKE	192*	8850	1946	31.9
CORA LAKES	193*	8400	1939	36.7
BADGER FLAT	346	8300	1960	31.5
NELLIE LAKE	194	8000	1944	36.0
LAKE THOMAS A EDISON	324	7800	1958	15.8
CHILKOOT LAKE	196	7450	1930	37.3
TAMARACK CREEK	347	7250	1960	25.7
FLORENCE LAKE	198	7200	1930	8.2
CHILKOOT MEADOW	197	7150	1930	37.0
CLOVER MEADOW	200*	7000	1939	23.0
HUNTINGTON LAKE	199	7000	1930	19.3
JACKASS MEADOW	201*	6950	1939	23.5
CHIQUITO CREEK	202*	6800	1939	21.9
POISON MEADOW	204	6800	1944	25.2

8. SNOW SURVEY DATA
AVERAGE WATER CONTENT OF SNOW, INCHES
APRIL 1st MEASUREMENTS
NORTH SIERRA REGION (NSR)
(CCSS, 1985 AND 1986)

AREA, DRAINAGE BASIN, AND SNOW COURSE	CALIF. NUMBR. (1)	ELEV IN FEET	RECORD BEGAN	AV APR 1 WC (2)
CENTRAL VALLEY AREA				
FEATHER RIVER				
LOWER LASSEN PEAK	47	8250	1930	80.0
KETTLE ROCK	361	7300	1965	25.0
MOUNT DYER 1	48	7100	1930	25.4
GRIZZLY	359	6900	1965	31.8
EUREKA BOWL	279	6800	1948	44.3
PILOT PEAK	388*	6800	1972	49.3
CHURCH MEADOWS	75	6700	1931	32.1
MOUNT HOUGH	360	6700	1965	31.8
ROWLAND CREEK	280	6700	1950	17.9
THREE LAKES	53*	6250	1930	39.9
EUREKA LAKE	52	6200	1939	33.1
HARKNESS FLAT	51*	6200	1930	28.8
MOUNT DYER 2	290	6050	1952	17.2
MILL CREEK FLAT	54*	5900	1930	39.7
FREDONYER PASS NO. 3	387	5880	1972	3.0
FRENCHMAN COVE	353	5800	1963	2.7
FREDONYER PASS 1	50*	5750	1930	8.7
ABBEY	355	5650	1963	9.8
ANTELOPE RIDGE	354	5650	1963	3.8
LETTERBOX	49*	5600	1940	30.4
MOUNT STOVER	55	5600	1931	16.4
BROWNS CAMP	56	5400	1937	24.5
FEATHER RIVER MEADOWS	58	5400	1930	23.1
WARNER CREEK	59*	5100	1930	15.9

AREA, DRAINAGE BASIN, AND SNOW COURSE	CALIF. NUMBR. (1)	ELEV IN FEET	RECORD BEGAN	AV APR 1 WC (2)
CENTRAL VALLEY AREA				
STONY CREEK				
ANTHONY PEAK	62	6200	1944	29.6
YUBA RIVER				
CASTLE CREEK 5	65	7400	1946	33.3
MEADOW LAKE	66	7200	1920	54.5
RED MOUNTAIN	67*	7200	1918	48.8
ENGLISH MOUNTAIN	68	7100	1927	44.0
DONNER SUMMIT	69*	6900	1910	39.5
FURNACE FLAT	76*	6700	1918	46.8
YUBA PASS	74	6700	1937	31.0
FINDLEY PEAK	78	6500	1927	29.3
LAKE FORDYCE	77*	6500	1918	40.1
ROBINSON COW CAMP	389*	6480	1972	47.2
SUNNYSIDE MEADOW	390*	6200	1972	60.7
CISCO	80	5900	1918	26.6
CHAPMAN CREEK	372	5850	1968	25.4
BOWMAN LAKE	83	5650	1927	21.7
LEXINGTON	391	5600	1972	34.1
GIBSONVILLE	277	5400	1950	30.9
LAKE SPAULDING	85	5200	1927	24.0
LAKE SPAULDING 2	409	5200	1976	15.7

8. SNOW SURVEY DATA
AVERAGE WATER CONTENT OF SNOW, INCHES
APRIL 1st MEASUREMENTS
NORTH SIERRA REGION (NSR)
(CCSS, 1985 AND 1986)
(CONT.)

AREA, DRAINAGE BASIN, AND SNOW COURSE	CALIF. NUMBR. (1)	ELEV IN FEET	RECORD BEGAN	AV APR 1 WC (2)
CENTRAL VALLEY AREA				
AMERICAN RIVER				
UPPER CARSON PASS	106*	8500	1930	35.2
LOWER CARSON PASS	331	8400	1951	39.2
CAPLES LAKE	107	8000	1939	30.9
ALPHA	365*	7600	1965	37.1
LOST CORNER MOUNTAIN	333*	7500	1959	36.3
ECHO SUMMIT	108	7450	1940	36.7
LAKE AUDRAIN	110	7300	1941	36.5
DARRINGTON	111	7100	1941	30.7
SILVER LAKE	109*	7100	1930	22.7
WRIGHTS LAKE	316*	6900	1956	34.4
PHILLIPS	113	6800	1941	29.3
LYONS CREEK	320	6700	1937	33.7
HUYSINK	115	6600	1937	46.7
TAMARACK FLAT	289	6550	1939	29.0
WABENA MEADOWS	114	6300	1937	43.3
MIRANDA CABIN	369	6200	1967	43.0
ONION CREEK	120	6100	1937	21.9
DIAMOND CROSSING	371	6050	1967	26.5
SIXMILE VALLEY	123	5750	1930	23.6
TALBOT CAMP	122	5750	1940	21.7
STRAWBERRY	124	5700	1942	8.5
ROBBS VALLEY	322	5600	1932	21.2
CARPENTER FLAT	128	5300	1946	17.3
ICE HOUSE	127	5300	1932	9.4

AREA, DRAINAGE BASIN, AND SNOW COURSE	CALIF. NUMBR. (1)	ELEV IN FEET	RECORD BEGAN	AV APR 1 WC (2)
CENTRAL VALLEY AREA				
MOKELUMNE RIVER				
HIGHLAND MEADOW	323*	8800	1952	47.9
TRAGEDY CREEK	364	8150	1965	46.6
BLUE LAKES	129*	8000	1918	35.4
WHEELER LAKE	131	7800	1937	53.6
PACIFIC VALLEY	132*	7500	1930	38.4
CORRAL FLAT	133	7200	1938	41.2
PODESTA	363	7200	1965	46.7
BEAR VALLEY RIDGE 1	134*	6700	1930	25.3
LUMBERYARD	135	6500	1937	32.1
HAMS STATION	136	5500	1937	7.8
STANISLAUS RIVER				
DEADMAN CREEK	345*	9250	1960	35.7
CLARK FORK MEADOW	344*	8900	1960	40.0
GIANNELLI MEADOW	427	8400	1984	48.9
LOWER RELIEF VALLEY	138*	8100	1930	40.0
SODA CREEK FLAT	139*	7800	1931	22.5
STANISLAUS MEADOW	384	7750	1971	48.3
EAGLE MEADOW	140*	7500	1931	24.9
HERRING CREEK	142	7300	1937	29.8
RELIEF DAM	143*	7250	1930	20.4
BLOODS CREEK	416	7200	1978	37.6
GARDNER MEADOW	415	6800	1978	32.3
SPICERS	144	6600	1937	29.5
HELLS KITCHEN	373	6550	1968	24.7
BLACK SPRING	386	6500	1971	25.7
NIAGARA FLAT	145	6500	1930	21.1
DORRINGTON	149	4750	1938	5.0

9. PRECIPITATION STATIONS UTILIZED FOR THE SUMMER EPISODIC EVENTS AND STATION ELEVATIONS (NOAA)

STATION	ELEVATION (ft.)
North Sierra Nevada	
1) Truckee Ranger Station	5995
2) Tahoe City Station	6230
3) Sagehen Creek Station	6337
Central Sierra Nevada	
1) Twin Lakes Station	8000
2) Gem Lake	8970
3) Ellery Lake	9645
South Sierra Nevada	
1) Lodgepole Station	6735
2) Grant Grove	6600

10. DATA COLLECTION FOR THE SUMMER EPISODIC EVENTS RAIN INTERARRIVAL TIME AND AMOUNT OF PRECIPITATION (NOAA)

Lodgepole Station

DATE OF EVENT	AMOUNT OF PPT. (in.)	RAIN INTERARRIVAL TIME (days)
7/8-7/10/83	0.58	57
7/15-7/19/83	1.56	3
7/14/84	0.16	67
7/16-7/18/84	1.42	11
7/13-7/24/84	0.64	1
7/20/85	0.23	47
7/22-7/25/86	0.57	41
8/21/86	0.11	26
7/14/87	0.01	34
8/25/87	0.05	41

Grant Grove Station

DATE OF EVENT	AMOUNT OF PPT. (in.)	RAIN INTERARRIVAL TIME (days)
8/8/83	0.07	57
8/18-8/21/83	0.49	2
7/13-7/14/84	0.05	26
7/22-7/23/84	0.57	3
8/16/84	0.2	23
7/17/85	0.04	43
7/22-7/23/86	0.06	51
8/21/86	0.1	28
8/31/87	0.24	84

Twin Lakes Station

DATE OF EVENT	AMOUNT OF PPT. (in.)	RAIN INTERARRIVAL TIME (days)
8/7-8/8/83	0.07	50
8/14/83	0.41	3
8/19-8/21/83	0.48	1
8/30-8/31/83	1.50	8
7/16-7/17/84	0.92	30
7/10/85	0.12	37
8/17/85	0.28	20
7/21-7/26/86	2.2	28
8/20/86	0.08	24
7/14/87	0.11	17
8/30/87	0.03	46

Ellery Lake Station

DATE OF EVENT	AMOUNT OF PPT. (in.)	RAIN INTERARRIVAL TIME (days)
8/3-8/5/83	0.16	40
7/17-7/11/84	0.16	13
7/18/84	2.26	6
8/21/84	1.52	4
7/20/85-7/27/8	0.94	7
8/15/85	0.08	18
7/23-7/26/86	1.19	37
8/17/86	0.8	21
7/1/87	0.06	14
7/15-7/16/87	0.64	8

Tahoe City Station

DATE OF EVENT	AMOUNT OF PPT. (in.)	RAIN INTERARRIVAL TIME (days)
7/21/83	0.13	20
8/8-8/11/83	0.14	36
8/15-8/16/83	0.44	3
7/16-7/17/84	0.11	29
8/22/84	0.02	28
7/22/85	0.21	48
8/18/85	0.10	13
8/31/85	0.01	12
7/23/86	0.59	39
8/20/86	0.02	24
7/13/87	0.04	11

Gem Lake Station

DATE OF EVENT	AMOUNT OF PPT. (in.)	RAIN INTERARRIVAL TIME (day)
8/8-8/11/83	0.38	55
8/14-8/19/83	0.58	2
8/30-8/31/83	0.94	1
7/5/84	0.14	17
7/17-7/20/84	0.42	1
7/30-8/1/84	0.98	4
7/19/85	0.06	28
7/23/86	0.08	52
8/28/86	0.02	33
8/23/87	0.02	28
7/16/87	0.02	12

Truckee Ranger Station

DATE OF EVENT	AMOUNT OF PPT. (in.)	RAIN INTERARRIVAL TIME (days)
7/2/83	0.09	20
8/9-8/11/83	0.27	37
8/15-8/16/83	1.17	3
7/22-7/23/84	0.68	4
7/6/84	0.03	19
7/18/84	0.13	12
8/22/84	0.05	21
7/21-7/22/85	0.08	30
8/18/85	0.04	21
8/30/85	0.06	11
7/22-7/27/86	0.47	41

Sagehen Station

DATE OF EVENT	AMOUNT OF PPT. (in.)	RAIN INTERARRIVAL TIME (days)
7/2/83	0.05	20
7/10/83	0.03	38
7/13-7/14/83	0.70	2
7/19-7/21/83	0.47	3
7/5/84	0.11	19
7/23-7/24/84	0.67	5
8/21/84	0.1	20
7/22/85	0.17	31
7/25-7/26/85	0.44	3
8/17/85	0.02	21
8/30/85	0.12	12
7/21/86	0.02	37
7/1/87	0.06	15
7/17-7/18/87	0.09	15

11. HYDROGEN ION CONCENTRATION OF PRECIPITATION DURING THE SUMMER SEASON
NADP and CARB Precipitation Stations

STATION	DATE	HYDROGEN ION (ueq/L)
Giant Forest	7/22-7/29/80	3.98
Giant Forest	7/21-7/27/82	64.57
Giant Forest	8/3-8/10/82	11.22
Giant Forest	8/24-8/31/82	42.68
Giant Forest	8/2-8/9/83	36.31
Giant Forest	8/9-8/16/83	19.95
Giant Forest	7/11-7/17/84	16.98
Giant Forest	7/17-7/24/84	28.18
Giant Forest	8/14-8/21/84	10.0
Giant Forest	7/22-7/29/86	11.48
Giant Forest	8/19-8/26/86	28.84
Mammoth Mountain	8/27-9/3/85	1.29
Mammoth Mountain	7/22-7/29/86	13.18
Yosemite National Park	8/3-8/10/82	1.2
Yosemite National Park	8/24-8/3/82	33.1
Yosemite National Park	8/9-8/16/83	5.25
Yosemite National Park	8/16-8/23/83	28.18
Yosemite National Park	8/30-9/6/83	24.0
Yosemite National Park	7/10-7/17/84	1.07
Yosemite National Park	7/17-7/24/84	0.7
Yosemite National Park	8/21-8/28/84	1.32
Yosemite National Park	8/13-8/20/85	19.95
Yosemite National Park	8/27-9/3/85	2.04
Lake Tahoe	7/22-7/26/86	19.95
Lake Tahoe	7/16-7/23/85	12.59
Lake Tahoe	7/23-7/30/85	12.3
Lake Tahoe	8/13-8/20/85	13.49
Lake Tahoe	8/27-9/4/85	12.02
Soda Springs	8/27-9/3/85	18.20
Soda Springs	7/22-7/30/86	30.2
Soda Springs	8/15-8/26/86	37.15